ERRATA[1]
for the third and fourth printings of
Doppler Radar and Weather Observations, Second Edition-1993
Richard J. Doviak and Dusan S. Zrnic'
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Page	Para.	Line	Remarks: Paragraph 0 is any paragraph started on a previous page that carries over to the current page. A sequence of dots is used to indicate a logical continuation to existing words in the textbook (e.g., see errata for p.14; or that for p.76; etc.)
xix		θ	modify definition to read: "is the zenith angle (Fig. 3.1); also the angle from the axis of a circularly symmetric beam (p. 34); also potential energy
14	2	2	change to read: "…index $n = c/v$ with height (or, because the relative permeability μ_r of air is unity, on the change of relative permittivity, $\varepsilon_r = \varepsilon/\varepsilon_o = n^2$, with height).
15	1	7	insert the reference (Born and Wolf, 1964, p. 87)
17	1	2-6	line 2, change "T=300 K" to "T=290 K"; line 4, change this equation to read: $N \approx 0.268\times(10^3 + 1.66\times10^2) \approx 312$; and line 6 change "1.000300" to "1.000312".
30	2	9	replace the italicized "*o*" from the first entry of the word "oscillator" with a regular "o", but italicize the "o" in the second entry of the word "*o*scillator"
	3	7	delete the parenthetical phrase
34	Eqs.3.2		replace D with D_a
35	1	9	at the end of the last sentence add: with origin at the scatterer.

1 Updates to the errata for the 3rd and 4th printings are periodically posted on NSSL's website at nssl.noaa.gov. Click Quick Links to Publications, Recent Books, and Errata 2nd edition, 3rd and 4th printings. Following the errata are Supplements that clarify or extend the book text.

The Dover Edition is a copy of the 1st and 2nd printings (not the 3rd and 4th printings as stated in the preface to the Dover edition) and errata to those printings, also at the same website, are not updated. For updates, the reader should refer to these errata.

	2	10	the equation on this line should read: $$\sigma_b = \sigma_{bm}\left(1 - \sin^2\psi / \sin^2\theta\right)^2 \cos^4[(\pi/2)\cos\theta] / \sin^4\theta$$
	Eq.(3.6)		and on the line after this equation, change “K_m” to “K_w”
36	0	7	delete “$\|K_m\|^2 \equiv$”
		9	change the end of this line to read: “Ice water has a $\|K_w\|^2 \equiv$”
40	Eq.(3.14b)		replace subscript “m” with “w”
46	1	7	change to read: “…, and that *g* accounts for losses in the antenna, the radome, and in the transmission lines from the antenna to the point where P_t and P_r are measured.
47	Table 3.1		change title to read: “The *nex*t generation *rad*ar, NEXRAD (WSR-88D), Specifications” change “Beam width” to “Beamwidth” change footnote *b* to read: “Initially the first several radars transmitted circularly polarized waves, but now all transmit linearly polarized waves”. Change footnote *c* to read: “Transmitted power, antenna gain, and receiver noise power are referenced to the antenna port, and a 3 dB filter bandwidth of 0.63 MHZ is assumed.
61	Eq.(3.40b)		place $\pm$ before v_a
	0	14	last line change to “velocity limits (Chapter 7).”
68	3	7-8	change to read as: “…is thus the expected power $E[P(\tau_s)]$.”
68	4	1	change to “$E[P(\tau_s)]$ does not change…”
69	0	6, 10	Change $\overline{P}(\tau_s)$ to $E[P(\tau_s)]$.
71	Eqs.(4.4a,b)		insert $(1/\sqrt{2}\ )$ in front of the sum sign in each of these equations
	3	6	replace “p. 418” with “p. 498”.
	Eq. (4.6)		delete the first “2”
72	0	4	change to: “..and a mean or expected value $E[P(\tau_s)] = 2\sigma^2$.”

	2	1	change $\overline{P}(\tau_s)$ to $E[P(\tau_s)]$
		3	remove footnote
73	Eq. (4.11)		change “ $\overline{P}(\boldsymbol{r}_0)$ ” to “$E[P(\boldsymbol{r}_0)]$”.
74-75	Eqs. (4.12), (4.14), (4.16):		change “ $\overline{P}(\boldsymbol{r}_0)$ ” to “$E[P(\boldsymbol{r}_0)]$”.
75	1	6	change to “$G(0) =1$”
	2	16	change (4.12) to (4.14)
		18	change “ $\overline{P}(\boldsymbol{r}_0)$ ” to “$E[P(\boldsymbol{r}_0)]$”.
76	Fig.4.5		change second sentence in caption to read: “The broad arrow indicates sliding of....”
77	0	12	change “mean” to “expected”
		13	change “ $\overline{P}(\tau_s)$ ” to “ $E[P(\tau_s)]$ ”
	Eq. (4.21)		change “ $\overline{P}(\tau_s)$ ” to “ $E[P(\tau_s)]$ ”
	Eq. (4.22)		delete $\equiv \lvert W(r) \rvert^2$
78	Fig. 4.7		change the argument ‘r’ in $\lvert W(r) \rvert^2$ to ‘ $\frac{c\tau_s}{2} - r$ ’
79	2	3	change to: “…a scatterer at *r* has the approximate range-dependent…”
		8-9	change to: “…the weighting function about its peak at any range $r = r_0$.”
82	Eq.(4.31)		delete the subscript “w” on Z
	Eq.(4.32)		delete the subscript “w” on Z
	Eq. (4.34)		change “ $P(\bar{\boldsymbol{r}}_0)$ ” to “$E[P(\boldsymbol{r}_0)]$”.
	Eq. (4.35)		change “ $\overline{P}(\mathrm{mw})$ ” to “$E[P(\mathrm{mw})]$”
	1	9	should read: “.. is the *reflectivity factor* of spheres.”
83	Eq.(4.38)		subscript “τ” should be the same size as in Eq.(4.37).

84	Eqs. (4.39), (4.43)		change "$\overline{P}(\boldsymbol{r}_0)$" to "$E[P(\mathbf{r}_0)]$".
85	0	4	change "$\overline{P}(\boldsymbol{r}_0)$" to "$E[P(\mathbf{r}_0)]$".
	Problem 4.1		change "$\overline{P}$" to "$E[P]$" in two places.
108	1	1	change "stationary" to "steady"
	1	11	change "$d\overline{P}$" to "$E[dP]$".
	Eq. (5.42)		change "$d\overline{P}(v)$" to "$E[dP(v)]$
		15	change "$\overline{P}(\mathbf{r}_0,v)$" to" $E[\Delta P(\mathbf{r}_0,v)]$"
	Eq.(5.43)		change "$\overline{P}(\mathbf{r}_0,v)$" to" $E[\Delta P(\mathbf{r}_0,v)]$"
	3	2-3	change to read: "…..by new ones having different spatial configurations, *the estimates* $\hat{S}(\mathbf{r}_o,v)$ *of* …"
109	Eq.(5.45)		change "$\overline{P}(\mathbf{r}_0)$" to "$E[P(\mathbf{r}_0)]$"
	4	1	add subscript "I" to $\overline{\eta}$ so it reads as "$\overline{\eta}_I(\mathbf{r}_0)$"
	Eq.(5.46a)		add subscript "I" to $\overline{\eta}$ on the left side of this equation.
			Change footnote "4" to read: "The overbar, without the subscript "I", denotes a reflectivity *and* $I_{\mathbf{n}}(\mathbf{r_0},\mathbf{r_1})$ weighted spatial average."
113	1	1-4	change to read: "Assume scatterer velocity is the sum of steady $v_s(\mathbf{r})$ and turbulent $v_t(\mathbf{r},t)$ wind components. Each contributes to the width of the power spectrum (even uniform wind contributes to the width because radial velocities $v_s(\mathbf{r})$ vary across V_6; steady wind also brings new...."
	2, 3	10, 3	delete the sentences beginning on line 10 in paragraph 2 with "Furthermore, we assume..." and ending in paragraph 3, line 3 with "...scatterer's axis of symmetry)."
	Eq. (5.59a)		change to:

$$
\begin{aligned}
R(mT_s) &= E[V^*(\tau_s,0)V(\tau_s,mT_s)] \\
&= E\left[\sum_i \sum_k F_i^*(0)A_i^*(0)F_k(mT_s)A_k(mT_s)\exp\{j(\phi_i - \phi_k - 4\pi v_k mT_s / \lambda\}\right] \qquad (5.59\text{a}) \\
&= \sum_k E[A_k^*(0)A_k(mT_s)F_k^*(0)F_k(mT_s)\exp\{-j4\pi v_k mT_s/\lambda\}]
\end{aligned}
$$

Following this equation the text to the end of the paragraph should read as follows:

Expectations of the off-diagonal terms of the double sum are zero because the phases ($\varphi_i - \varphi_k$) are uniformly distributed across 2π; thus the double sum reduces to a single one. To simplify further analysis, assume that the scatterer's cross section is independent of its position and velocity, and that F_k does not change appreciably [i.e., $F_k(mT_s) \approx F_k(0)$] while the scatterer moves during the time mT_s. But A_k varies randomly in time (i.e., hydrometeors oscillate and change their orientation relative to the electric field). Thus Eq. (5.59a) reduces to

$$
R(mT_s) = \sum_k B_k(mT_s)\,|F_k|^2\; E[\exp\{-j4\pi v_k mT_s/\lambda\}] \qquad (5.59\text{b})
$$

where

$$
B_k(mT_s) = E[A_k^*(0)A_k(mT_s)] \qquad (\text{m}^2)
$$

Because $R(0)$ is proportional to the expected power $E[P]$, and because

$$
E[P(\mathbf{r}_0)] = \sum_k \sigma_{bk} I(\mathbf{r}_0, \mathbf{r}_k) \qquad (5.59\text{c})
$$

[i.e., from Eq. (4.11)], where σ_{bk} is the expected backscattering of the k^{th} hydrometeor, it follows that $B_k(0)$ is proportional to σ_{bk} and thus $B_k(mT_s)$ gives the loss…."

114	2	2-4	modify to read: "...mechanisms in Eq. (5.59b) act through product terms. Furthermore, the *k*th scatterer's radial velocity v_k can be expressed as the sum of the velocities due to steady and turbulent winds that move the scatterer from one range position..."
		6-9	delete these lines and replace with: "…Eq. (5.59b), the velocities $v_s(\boldsymbol{r})$ and $v_t(\boldsymbol{r}, t)$ associated with steady and turbulent winds can each be placed into separate exponential functions that multiply one another. Thus the expectation of the product can be expressed by the product of the exponential containing $v_s(\boldsymbol{r})$ and the expectation of the exponential function containing $v_t(\boldsymbol{r}, t)$; these exponential functions are correlation functions. The Fourier transform of $R(mT_s)$, giving the composite spectrum $S(f)$, can then be expressed as a convolution of the spectra associated with each of the three correlation

functions. There are other de-correlating mechanisms (e.g., differential terminal velocities, antenna motion, etc.,) that increase the number of correlation functions and spectra to be convolved. It is shown that, ….”

115 3 1 “R” in “R_k” should be italicized to read “R_k”

9 change “Eq. (5.59a)” to “Eq. (5.59b)”

14 Change these lines and Eqs. (5.64) to read: “Because the correlation coefficient can be related to the normalized power spectrum $S_n(f)$ by using Eq. (5.19), and because the Doppler shift $f = -2v/\lambda$, $\rho(mT_s)$ can be expressed as

$$\rho(mT_s) = \int_{-\lambda/4T_s}^{\lambda/4T_s} \frac{2}{\lambda} E\left[S_n^{(f)}(-2v/\lambda\right] e^{-j4\pi mT_s/\lambda} dv = \int_{-v_a}^{v_a} E\left[S_n(v)\right] e^{-j4\pi vmT_s/\lambda} dv \qquad (5.64)$$

116 0 1-4 change these lines to read: where $S_n^{(f)}(-2v/\lambda)$ is the normalized power spectrum in the frequency domain folded about zero, $S_n(v)$ is the normalized power spectrum in the Doppler velocity domain, and the two power spectra are related as

$$S(v) = \frac{2}{\lambda} S^{(f)}(-2v/\lambda) . \qquad (5.65)$$

By equating Eq. (5.63) to Eq. (5.64), and assuming all power is confined within the Nyquist limits, $\pm v_a$, it can be concluded that

$$p(v) = E\left[S_n(v)\right]. \qquad (5.66)$$

1 1-3 change to read: “Thus, for homogeneous turbulence, at least homogeneous throughout the resolution volume V_6, the *expected* normalized power spectrum is equal to the velocity probability distribution. Moreover, it is independent of reflectivity and the angular and range weighting functions.

1 3-7 Delete the last two sentences beginning with “Although, in deriving….”

116 2 15-21 the two sentences beginning with “Because the cited spectral …..” should be modified to read: “If turbulence, hydrometeor oscillation/wobble, and terminal velocities are locally homogeneous (i.e., statistically homogeneous over V_6) and independent spectral broadening mechanisms, it can be shown that the square of the composite velocity spectrum width σ_v^2 can be expressed as the sum

$$\sigma_{\mathrm{v}}^2 = \sigma_{s\alpha}^2 + \sigma_{\mathrm{t}}^2 + \sigma_{\mathrm{o}}^2 + \sigma_{\mathrm{d}}^2 . \tag{5.67}$$

where $\sigma_{s\alpha}^2$ is due to the combined effect of shear and antenna motion, σ_d^2 to different ….”

23 this line should be changed to read as “…..airborne radar, $\sigma_{s\alpha}$ principally depends on antenna rotation and shear.

117 1 7 end this paragraph at the end of the sentence: “…to the beam center.”

7-8 begin a new paragraph by modifying these lines to read: “If there is no radial velocity shear, and if the antenna pattern is Gaussian…..”

Eq. (5.69) change to read:

$$\sigma_{s\alpha}^2 \to \sigma_{\alpha}^2 = (\alpha\lambda \cos\theta_e / 2\pi\theta_1)^2 \ln 2 \tag{5.69}$$

2 1 change this line to read: “Assume the beam is stationary. We shall prove that the term $\sigma_{s\alpha}^2 \to \sigma_s^2$ is composed of three….”

4-7 Modify these lines to read: “where the terms are due to shear of v_s along the three spherical coordinates at $\mathbf{r}_0$. In this coordinate system (5.70) automatically includes…”

9 change to read: “the so-called beam-broadening term;....”

117-118; 3 Replace the text in this paragraph up to and including Eq. (5.75) with:

“Spherical coordinate shears of v_s can be directly measured with the radar and it is natural to express σ_s^2 in terms of these shears. If the resolution volume V_6 dimensions are much smaller than its range r_0, and angular and radial shears are uniform, v_s can be expressed as

$$v_s - v_o \approx k_\phi r_o \sin\theta_o(\phi - \phi_o) + k_\theta r_o(\theta - \theta_o) + k_r(r - r_o) \tag{5.71}$$

provided $\theta_1 << 1$ (radian) and $\theta_0 >> \theta_1$, where

$$k_\phi \equiv \frac{1}{r_o \sin\theta_o}\frac{dv_s}{d\phi}, \quad k_\theta \equiv \frac{1}{r_o}\frac{dv_s}{d\theta}, \quad k_r \equiv \frac{dv_s}{dr} \tag{5.72}$$

are angular and radial shears of v_s. Angular shears, defined as the Doppler (radial) velocity change per differential arc *length* (e.g., $r_o\sin\theta_0 d\varphi$), are present even if Cartesian shears are non-existent, and they are functions of $\mathbf{r}_0$. For example, if wind is uniform (i.e., has constant Cartesian components u_0, v_0, w_0),

$$\frac{dv_s}{d\phi} = (u_0\cos\phi_0 - v_0\sin\phi_0)\sin\theta_0; \frac{dv_s}{d\theta} = (u_0\sin\phi_0 + v_0\cos\phi_0)\cos\theta_0 - w_0\sin\theta_0;\ k_r = 0 \quad (5.73)$$

If reflectivity is uniform and the weighting function is product separable and symmetric about $\mathbf{r}_0$, substitution of Eq. (5.71) into Eq. (5.51) produces

$$\sigma_s^2(\boldsymbol{r}_0) = \sigma_{s\theta}^2 + \sigma_{s\phi}^2 + \sigma_{sr}^2 = k_\theta^2 r_0^2\sigma_\theta^2 + k_\phi^2 r_0^2\sigma_\phi^2(\theta_0)\sin^2\theta_0 + k_r^2\sigma_r^2 . \quad (5.74)$$

Because lines of constant ϕ converge at the vertical, the second central moment $\sigma_\phi^2(\theta_0)$ of the two-way azimuthal power-pattern, for the elevation over azimuth type beam positioners used with weather radars, is $\sigma_\phi^2(\theta_0) = \sigma_\phi^2(\pi/2)/\sin^2\theta_0$, where $\sigma_\varphi^2(\pi/2)$ is the intrinsic azimuthal beamwidth; σ_r^2 is the second central moment of $|W(r)|^2$. For circularly symmetric Gaussian patterns,

$$\sigma_\theta = \frac{\theta_1}{4\sqrt{\ln 2}}; \quad \sigma_\phi(\theta_0) = \frac{\theta_1}{4\sqrt{\ln 2}}\frac{1}{\sin\theta_0} \quad (5.75)$$

118 0 after Eq. (5.76) add: "The above derivation ignored effects of beam scanning during the dwell time MT_S. If the beam scans at an azimuth rate α, it can be shown that

$$\sigma_{s\alpha}^2 = \sigma_\alpha^2 + k_\theta^2 r_0^2\sigma_\theta^2 + k_\phi^2 r_0^2\sigma_{\phi e}^2(\pi/2,\alpha) + k_r^2\sigma_r^2 \quad (5.77)$$

where $\sigma_{\phi e}(\pi/2,\alpha) = \theta_{1e}(\alpha)/4\sqrt{\ln 2}$, is the azimuthal beamwidth effectively broadened by antenna rotation during MT_S, and $\theta_{1e}(\alpha)$ is the effective one-way half-power azimuthal width, a function of αMT_s (Fig. 7.25).

125 1 1 replace "average" with "expected"

Eq. (6.5) append to this equation the footnote: "In chapter 5 ρ is the complex correlation coefficient. Henceforth it represents the magnitude of this complex function."

4 5 remove the overbar on P, S, and N

126	0	1	change to read: "power estimate $\hat{P}$ is reduced……variance of the P_k.."
	3	2-4	the second sentence, modified to read, "The P_k values of meteorological interest...meeting this large dynamic range requirement", should be moved to the end of the paragraph 1
		5	change "$\overline{P}$" to "S".
127	0	1-2	remove the overbar on P in the three places
	3	1	remove the overbar on Q
		8	delete the citation "(Papoulis, 1965)"
128	1	8	change "unambiguous" to "Nyquist"
	2	4-7	rewrite the second and third sentences after Eq. (6.12) as: "The variance of the estimates $\hat{S}$, each obtained by averaging M un-weighted signal power samples, is calculated using the distribution given by Eq. (4.7) to calculate the single sample variance σ_Q^2 in Eq. (6.9) (in using Eq. (4.7) we set [2] $P \to \hat{S}$ because noise power is assumed to be zero); this gives $\sigma_Q^2 = S^2$. Thus the variance of the M sample average is, from Eq.6.10, S^2 / M_I where M_I is calculated from Eq. (6.12)."
	3	1-2	change to read "To estimate S in presence of receiver noise, we need to subtract....."
		4-9	remove overbars on P, N, and S
129	0	5-6	change last sentence to read: "....then the number of independent samples can be determined using an analysis similar to....."
130	Table 6.1		add above **"Reflectivity factor calculator"** the new entry "**Sampling rate",** and in the right column on the same line insert "0.6 MHz". Under "**Reflectivity factor calculator**", "Range increment" should be "0.25 km" and not "1 or 2 km". But insert as the final entry under "**Reflectivity factor calculator**" the entry "Range interval Δr", and on the same line insert "1 or 2 km" in the right column.

2 In chapter 4 the diacritical '^' is not used to designate an estimate, but *P*, the instantaneous power, can be assumed to be a single sample estimate. In Chapter 6 power *P*, without the diacritical mark, is the mean or expected power.

136	footnote		change to read: "To avoid occurrence of negative $\hat{S}$, only the sum in Eq. (6.28) is used but it is multiplied with $S\hat{N}R/(S\hat{N}R+1)$ "
137	2	1	delete "($\sigma_{vn} > 1/2\pi$)"
142	Eq.(6.42)		place a caret
155	3	3	in section 6.8.5 line 3, change "Because" to "If"
160	2	6	change "unambiguous velocity " to "Nyquist velocity"
171	0	3	T_s should be T_2
173	0	1	change to read: "…velocity interval $\pm v_m$ for this…."
	Eq. (7.6b)		place $\pm$ before v_m
	3	9-10	this should read: "…the desired unambiguous velocity interval. An unambiguous velocity interval v_m =…"
		11	change "unambiguous" to "Nyquist"
182	Eq.(7.12)		W_iW_{i+1} should be W_iW_{i+l}
197	1	1	"though" should be "through"
	2	4	"Fig.3.3" should be "Fig.3.2"
200	Fig.7.28		Caption should read: "The WSR-88D radiation pattern. The polarization was….. are specified to be below the dashed……on the main lobe. (Note the dashed lines are incorrectly drawn. They should extend…..".
201	0	2	"Norma" should be "Norman"
	Eq. (7.36)		change " $\overline{P}(r_0)$ " to " $E[P(\mathbf{r}_0)]$", and the upper integration limit to 2π
213	1		Change this paragraph to read: The Marshall-Palmer (M-P) data extend over a relatively short range of drop diameters (Fig. 8.3a). Earlier measurements (Laws and Parsons, 1943; Fig. 8.3b) that span a much larger range show that the drop size distributions (DSDs) at small drop diameters do not converge to a constant N_0 as suggested by Marshal and Palmer. The large increase in drop density at smaller diameters is also

			seen in the theoretical steady-state distributions derived by Srivastava (1971).
222	Eq. (8.18)		the differential "d*D*" on the left side of Eq.(8.18) must be moved to the end of this equation.
228	1	4	change Z_w to Z_e
	Eq.(8.24)		this equation should read as: $Z_i = (\lvert K_w\rvert^2/\lvert K_i\rvert^2)Z_e \qquad (8.24)$
	2	6	change to: "..to estimate the equivalent rainfall rate R_s (mm/hr) from the..."
		7	delete "with $Z_w = Z_e$"
232	0	10-11	change to: "...a microwave (i.e., λ= 0.84 cm) path, confirmed...."
234	Eq.(8.30)		right bracket "}" should be matched in size to left bracket "{"
244	2	1	change to read: "…phase shifts of the propagating wave can have.."
248	Eq.(8.57)		parenthesis ")" needs to be placed to the right of the term "(b/a"
249	Eq.8.58		$\cos^2\delta$ should be $\sin^2\delta$; replace k_o with k; p_v and p_h should be replaced with p_a and p_b respectively
	Eq.8.59a,b		change the subscripts "h" to "b", and "v" to "a"
	2	9	change to read: "p_a and p_b are the drop's susceptibility in generating dipole moments along its axis of symmetry and in the plane perpendicular to it respectively, and *e* its eccentricity,"
		12-13	rewrite as: "...symmetry axis, and Ψ is the apparent canting angle (i.e., the angle between the electric field direction for "vertically" polarized waves, **v** in Fig.8.15, and the projection of the axis of symmetry onto the plane of polarization). The forward scattering........"
		17	modify to read: "….$f_h = k^2 p_b$, and $f_v = k^2\,[(p_a-p_b)\sin^2\delta + p_b]$ (Oguchi, ..."
	3	4-5	Rewrite as: "Hence from Eqs.(8.58) an oblate drop has, for horizontal propagation and an apparent canting angle equal to zero, the following cross sections for h and v polarizations:"

268 Fig. 8.29			LDR_{hv} on the ordinate axis should be LDR_{vh}
	0	1,4	change LDR_{hv} to LDR_{vh} at the two places it appears in this paragraph.
269 Fig. 8.30			In the caption, change LDR_{hv} to LDR_{vh} at the two places it appears.
277	0	16	change "23000" to "230,000"
289	2	3	delete the sentence beginning with "In this chapter overbars…."
298	Fig.9.4a, b		here and elsewhere in the text, remove periods in time abbreviations (i.e., should be: "CST", not C.S.T.")
306	2	2	At the end of the sentence on this line, insert: "Radar measurements of wind are biased by the velocity of scatterers (e.g., hydrometeors, insects, etc.) relative to the wind. In this section we consider scatterers are perfect tracers of the wind but later (section 9.3.3) we introduce corrections for the bias caused by the hydrometeors' terminal velocity."
390	0	1	change to read "along the path ℓ of the aircraft, and $S_{ij}(K_\ell)$ is the Fourier transform of $R_{ij}(\ell)$. In contrast...."
393	1	11	the subscripts on $R_{11}(0)$ should be changed to $R_{ll}(0)$; (i.e., so that it is the same as the subscripts on the second "*D* " in line 19).
	Eq. (10.33)		place subscript l on C so that it reads C_l.
394	0	1	change to read: "where C_l^2 is a dimensionless parameter with a value of about 2."
	Eq.(10.37)		change to read: $R_{ii}(\rho, \tau_1 = 0) = R(0)[1 - (\rho / \rho_{oi})^{2/3}]$ (10.37)
398	1	12	change to read: "…of the weighting function I_n, and $\Phi_v(\mathbf{K})$ is the spatial spectrum of point radial velocities."
		17	change to read: "…antenna power pattern under the condition, $\theta_e = \pi/2 - \theta_0 << 1$, and…."
398 Eq. (10.48)			Change the subscripts "*ll*" to "11".
404	2	1	change to read: "….proportional to the radial component of turbulent kinetic energy,…"

	4	7	place an over bar on the subscript “u” in the next to last equation
409	3	2	change to read: “….must be interchanged with σ_r, and the second parameter (i.e., ½) in the argument of F must be changed to 2.
		5,6	change to read: “Using the series expansion for F to first order in $1-\frac{\sigma_\theta^2 r^2}{\sigma_r^2}$, the dissipation rate can be approximated by
412	2,3	2,1	delete the word “linear” in these two lines.
	2	5	change “polynomial surface” to “polynomial model”
		7	change “surface” to “model”
419	Fig. 10.18		the “-5/3” dashed line drawn on this figure needs to have a -5/3 slope. Furthermore, remove the negative sign on “s” in the units (i.e., m^3/s^{-2}) on the ordinate scale; this should read (m^3/s^2).
445	1	6	delete “time dependence of the”
453	1	10	delete “(s)” from “scatterer(s)”; subscript “c” in $\rho_{c,\|\|}$ should be replaced with subscript “B” to read $\rho_{B,\|\|}$
		12	a missing subscript on $\rho_{,\perp}$ should be subscript “B” so the term reads: $\rho_{B,\perp}$
Eqs. (11.105, &106)			the symbols $\|\|$&$\perp$ should also be subscripts, along with “B”, on the symbol “ρ” to read “$\rho_{B,\|}$” and “$\rho_{B,\perp}$”.
454	0	6	change “blob” and “blobs” to “Bragg scatterer” and “Bragg scatterers”
	Fig.11.11		caption should be changed to read: “........, a receiver, and an elemental scattering volume dV_c.”
456 Eq. (11.115)			bold “r” in the factor $W(\mathbf{r})$ needs to be unbolded
	Fig. 11.12		add a unit vector $\mathbf{a}_o$ drawn from the origin “**O**” along the line “r_0”.
458	2	4	make a footnote after $\sqrt{2}$ to read: z′ is the projection of r′ onto the z axis; not to be confused with z′ in Fig.11.12 which is the vertical of the rotated coordinate system used in section 11.5.4.

459	Eq.(11.125)		delete the subscript "c" in this equation, as well as that attached to ρ_{ch} in the second line following Eq.(11.125) so that it reads "ρ_h".
460	1	4-9	delete the third to fifth sentences in this paragraph and replace with the following: Condition (11.124) is more restrictive than (11.106); if (11.124) is violated the Fresnel term is required to account for the quadratic phase distribution *across the scattering volume*, whereas (11.106) imposes phase uniformity *across the Bragg scatterer*; this latter condition is more easily satisfied the farther the scatterers are in the far field (also see comments at the end of section 11.5.3).
464 Fig. 11.14			caption: the first citation is incorrect. It should read: "(data are from Röttger et al., 1981)". Furthermore, delete the last parenthetical expression: "(Reprinted with permission from ….)."
468	2	11	change "(11.109)" to "11.104"
475			Eq. (11.151) should be: $\lambda \geq \lambda_t = 10\pi(\nu^3 / \varepsilon)^{0.25}$
478	0	7	Change to read: "...the gain g. Then g, now the directional gain (Section 3.1.2), is related..."
493	1		delete the last sentence and make the following changes: 1) change lines 2 and 3 to read: "... $C_n^2 = 10^{-18}\,\mathrm{m}^{-2/3}$ (Fig.11.17), the maximum altitude to which wind can be measured is computed from Eq.(11.152) to be about 4.5 km." 2) change lines 4 and 5 to read: "…that velocity estimates are made with SNR = -19.2 dB (from Eq.11.153 for $T_s = 3.13\text{x}10^{-3}$ s), and that σ_v = 0.5m s^{-1}, SD(v) = 1 m s^{-1}, and a system temperature is about 200 K (section 11.6.3)."
	2	1-4	change to read: "Assuming that velocities could be estimated at SNRs as low as -35dB (May and Strauch, 1989), the WSR-88D could provide profiles of winds with an accuracy of about 1 m s^{-1} within the entire troposphere if C_n^2 values…"
		8; 9	change '"14' to '12'; change "able to measure" to "capable of measuring"
533		3	change "Hitchfeld" to "Hitschfeld"

SUPPLEMENTS

The following supplements are provided at the indicated places to clarify and/or extend the text of "Doppler Radar and Weather Observations", Second Edition-1993.

Page	Para.	Line	Remarks: Paragraph 0 is any paragraph started on a previous page that carries over to the current page.

Add to the List of Symbols:

E[x]	Expected value of the random variable 'x'; also <x>
$\hat{x}$	an M sample estimate of E[x],
$\bar{x}$	spatial average of 'x'

Page	Para.	Line	Remarks
3	3		At the end of this paragraph add: R. D. Hill (1990) cited work done by researchers at the Naval Research Laboratory suggesting the first pulse radar detection of aircraft might have been in December 1934.
31	Fig. 3.1		add θ_e to this figure.
33	1	4	change to read: "…and often its intensity (i.e., power density) versus…"
34	0		Note that the one-way radiation pattern of the WSR-88D radar (the network radar used by the Weather Service in the USA) is well approximated with

$$f^2(\theta) = \left(\frac{48.2 J_3(u)}{u^3} + \frac{0.32 J_1(u)}{u} \right)^2 \Big/ (1.16)^2 .$$

This agrees, down to about the -20 dB level, to within 2 dB of the pattern measured for NSSL's research WSR-88D at a wavelength of 0.111m. The pattern given by this equation is slightly broader (i.e., the 3 dB beamwidth calculates to about 1^o whereas the measured width is about 0.93^o). This analytical expression is that obtained if the reflector's aperture is illuminated with a power density $[1-4(\rho/D_a)^2]^4$ on a uniform illumination level producing at the reflector's edge a power density 17.2 dB below the peak. The 1st and 2nd sidelobe levels, calculated from the above expression, are 34.2 and 48.4 dB below the peak lobe at about 1.7^o and 2.5^o respectively; sidelobes beyond 3^o have relatively uniform levels that range from 56.3 (at 3^o) to 62 dB below the peak lobe at 10^o. Measured sidelobe levels (see Fig. 7.28), however, can be anywhere from a few dB to about 18 dB larger (the largest difference is at about 3^o). The increased measured levels are due to scatter and blockage from the feed and its supporting spars, distortions in the surface of the reflector, and scatter from objects (i.e., trees, buildings, etc.) on the antenna measurement range. Sidelobe levels are even larger (e.g., 25 dB above the theoretical level at 3^{o}) along measurement lines perpendicular to the feed supporting spars. But these enhanced levels, due to the blockage of radiation by the spars, are confined to relatively narrow angular sectors.

2 6 If the shape of the radiation pattern of a beam, not necessarily circularly symmetric, is well approximated by the product of two Gaussian functions, the maximum directional gain is

$$g_t' = \frac{1}{\sigma_\phi \sigma_\theta},$$

where σ_ϕ^2 and σ_θ^2 , assumed to be much smaller than 1 rad^2, are the second central moments of the two-way pattern expressed in normal form. The two-way pattern is the product of the transmitted radiation pattern and the receiving antenna's field of view pattern. Typically the same antenna is used for both functions, and thus the two-way pattern is $f^4(\theta) f^4(\phi)$. For the circularly symmetric pattern of the WSR-88D, the two-way pattern is $f^4(\theta) = \exp\{-\theta^2 / 2\sigma_\theta^2\}$. In terms of the one-way 3-dB pattern width θ_1, $\sigma_\theta = \theta_1 / 4\sqrt{\ln 2}$.

35 1 There are several definitions of cross sections. For example, $\sigma_d = \dfrac{S_r}{S_i} r^2$ is the *differential scatter cross section*; that is, it is the cross section *per unit* solid angle. Integration of $\sigma(\theta', \phi')$ over 4π steradians gives the *total scatter cross section* (see section 3.3).

36 0 2 Insert at the end of the first sentence: "It can be shown, using formulas presented in Section 8.5.2.4, that Eq. (3.6) has practical validity only if drops have an equivalent spherical diameter D_e less than 2 mm. Drops having D_e larger than 2 mm have backscatter cross sections differences larger than about 0.5 dB for horizontally and vertically polarized waves (i.e., $\sigma_h > 1.1\sigma_v$)."

38 0 1-2 change to read: "…flows in the forward or backward directions.

1 4 add at the end of this paragraph: "Furthermore, Probert-Jones (1984) demonstrated that internal resonances in electrically large low-loss spheres can generate greatly enhanced scatter in both the forward and backward directions.

39 1 5 — change to read as where l is ……loss factor due to…

42 Fig. 3.5 — Caption: Because there is considerable confusion concerning the use of the unit dBZ, and because some writers use dBz for the decibel unit of reflectivity factor Z, we present the following comment:

The logarithm decibel dB is not an SI unit. But dB has been accepted widely as a "unit" (e.g., Reference Data for Radio Engineers, 5th Edition, Howard W. Sams, publisher, division of ITT, p.3-3). The decibel is also recognized by international bodies such as the International Electrotechnical Commission (IEC). The IEC permits the use of the decibel with field quantities as well as power and this recommendation is followed by many national standards bodies. Moreover, according to SI rules, units should not be modified by the attachment of a qualifier. Nevertheless, appendages to dB have been *accepted in the engineering field* to refer the dB unit to a reference level of the quantity being measured. For example, dBm is the decibel unit of power and is equal to 10 $\log_{10} P/P_r$ where P is the power, in milliwatts, referenced to $P_r = 1$ milliwatt (e.g., Reference Data for Radio Engineers). Similarly, the parameter dBZ *has been accepted by the AMS* as the symbol for the "unit" decibel of reflectivity factor Z referenced to reflectivity factor $Z = 1\ \mathrm{mm^6 m^{-3}}$ (Glossary of Meteorology, 2nd Edition, 2000, American Meteorological Society).

43-44 — The range of validity of (3.17d) can be extended to shorter wavelengths by rewriting the last two lines on p.43 as: "For weather …… between 0.62 and 10 cm…."; then replacing the numerator in (3.17d) with 1.0×10^{-3}; rewriting the first two lines on p. 44 to read as "with and accuracy of about $\pm$ 10%, where……two-way attenuation of 0.41 dB…."

44 3 4 — Blake has more recently published (1986, in "Radar range performance analysis", 2nd ed., ARTECH House, Norwood, MA.) new values of attenuation in gases. For example, at λ = 10 cm, r = 200 km, $\theta_e = 0^o$, the two way loss is about 0.3 dB larger than that given in Fig.3.6.

p. 47 Table 3.1 — Because radome losses are specified, the correct interpretation of footnote *c* would be better insured by amending the errata for this footnote to read "Transmitted power, antenna gain (including radome loss), and …"

56 Eq. (3.34) — If the beam is passing through clouds and storms, Eq. (3.34) should be replaced by

$$T_s' = \left(1 - \frac{1}{\ell_c}\right)(1 - \chi + \chi\eta_r)T_c + \frac{1-\chi}{\ell_c}T_s + \chi(1-\eta_r)T_g + \frac{\chi\eta_r}{\ell_c}T_s$$

where ℓ_c and T_c are the cloud's attenuation and temperature.

58 1 4 — Change to read: "….effects is reached (Section 4.5)."

57	Fig. 3.11		For completeness, the ordinate should be labeled "Sky noise temperature T_s (K)"
64-121			Because Chapters 4 and 5 focus attention mainly on weather signals, changing power *P* to signal power *S* throughout these chapters should improve clarity. This suggestion is made because *P* is generally used to define signal *S* plus noise *N* power.
61 Eq. (3.40b)			Elsewhere in the book (e.g., pp.172, 173), we define v_a as the Nyquist velocity. It would be less confusing if v_a is replaced with v_N throughout the book; this change keeps one from calling v_a the unambiguous velocity which is confusing because all velocities in the interval $-v_N < v < v_N$ are unambiguously measured.
68	3	8	add: "The expected value is obtained by averaging over an ensemble of scatterer configurations having the same statistical properties (e.g., reflectivity factor)." The expectation operator *E*[x] in this book is used for ensembles of a variety of variables (e.g., velocity fields $v(\mathbf{r},t)$, scatterer configurations ξ, etc.). If the statistics are stationary, and assuming there is a velocity field that uniformly moves the scatterers, the expectation can be replaced with a time average. If statistics are not stationary, then the ensemble average must be made over ξ, and in this section we could have appended the subscript ξ to have $E_\xi[x]$ to emphasize this fact and to avoid subsequent possible confusion.
71	2, 3		An explanation for the √2 factors in Eqs. (4.4) and (4.6), and how power is related to σ^2 might be helpful. Because a lossless receiver is assumed, the sum of powers in the *I* and *Q* channels must equal the power at the input to the receiver (i.e., the synchronous detectors in Fig. 3.1). Because we have assumed the amplitude of the echo voltage at the receiver's input is *A* (e.g., Eq. (2.2b)), the amplitude of the signal in the *I* and *Q* channels must be $A/\sqrt{2}$. Furthermore, we can determine from Eq. (4.5) that the rms values of *I* and *Q* voltages equals σ (i.e., $I_{rms} = Q_{rms} = \sigma$). Thus the average power in each of the channels is σ^2, and the sum of the average powers in these two channels is 2 σ^2 which equals the expected power E[P] at the input to the receivers. The constants of proportionality (i.e., impedances) that relate voltage to power are assumed the same at all points in the receiver (e.g., at inputs to the *I* and *Q* channels).
72	2	1	here and in Eq. (4.8), we need to distinguish the expectation operator "*E*[x]" used in section 4.2 and 4.3, which strictly applies to an ensemble of

			scatterer configurations, from the expectation over the scatterer's cross section implied by Eq.(4.8). To emphasize this difference, we could have appended the subscript σ to the expectation operator in these first four lines of Section 4.4; then $E_\sigma[\| A_i \|^2]$ would apply to the i^{th} scatterer, not the ensemble of scatterer configurations. When we deal with a large number of scatterers we also need to take an ensemble average over all the scatterer configurations ξ to obtain the expected power. That is, the expectation operator in Eq. (4.9a) should be performed over both σ and ξ (or over time if statistics are stationary). This interpretation carries throughout the book. The sample mean (a finite time average) is what is typically measured; but this is an estimate of the expected value, and becomes the expected value in the limit as sample size grows to infinity (or the time average is infinitely long).
74	1	4	change to read: "….to its range extent, and if the polar axis of the spherical coordinate system (Fig. 3.1) is aligned with the beam axis (i.e., $\theta_0 = 0$), we can approximate Eq. (4.11) by…"
		8	change to read: "…by a Gaussian shape, $f^4(\boldsymbol{\theta}) = \exp(-\boldsymbol{\theta}^2 / 2\boldsymbol{\sigma}_\theta^2)$, we can show…"
		10	change to read: "where $\boldsymbol{\theta}_1 = 4\boldsymbol{\sigma}_\theta\sqrt{\ln 2} << 1$ is the …. of the one-way power pattern."
79	0	8	add at the end of this paragraph: Range r_0 is the range to the center of the radar's resolution volume defined in Section 4.4.4.
87 Sections 5.1			It should be noted that voltage V in the earlier parts of this section is not necessarily a random variable as is the weather signal. Section 5.1.2, and sections following it, focuses on random voltages.
95 Eq. (5.17)			Note that this equation is a biased estimate of the autocorrelation $R(l)$. To obtain an unbiased estimator, replace the M^{-1} multiplier with $(M\text{-}1)^{-1}$.
106-112			Because sections 5.2 and 5.2.1 stipulate that the velocity field is steady (i.e., time independent) we could have, in these two sections, appended the subscript 's' to '*v*' to emphasize that '*v*' is a steady wind, and to be consistent with later notation (i.e., errata on p. 113, line 1).
110 Eq.(5.50)			$\sigma_{\mathbf{v}}^2(\mathbf{r}_0)$ is sometimes defined as the variance of the mean normalized Doppler spectrum. In that case the Doppler spectrum is interpreted as showing the probability density of velocities. This is at best a questionable interpretation, because Doppler velocities are a composite of real and

apparent velocities (Fang and Doviak, JAOT, Dec. 2008, pp. 2245-2258).

112 2 10-12 change to read: "…turbulence, etc.) act independently as we now demonstrate."

114 Eq.(5.59b) follow this equation in the errata with the following explanatory comment: "The expectation operation in Eq.(5.59b), could be written as E_ξ to indicate the expectation is over an ensemble ξ of scatterer configurations as discussed on p.108. Furthermore, it would be clearer if we replaced $R_k(mT_s)$ in this equation and the one that follows it, with $B_k(mT_s)$ because $R_k(mT_s)$ has units of m^2, whereas $R(mT_s)$ is power.

Eq.(5.59c) Strictly for clarity, this equation should be written as

$$\mathrm{E}_{\xi}[P] = \sum_k \mathrm{E}_{\sigma}[\sigma_{\mathrm{b}k}] I(\mathbf{r_0}, \mathbf{r}_k)$$

Because P and $\sigma_{\mathrm{b}k}$ are random variables; P fluctuates as scatterers reconfigure themselves, and $\sigma_{\mathrm{b}k}$ fluctuates as the hydrometeor oscillates/wobbles. The subscript ξ indicates an ensemble average over various scatterer configurations; it also could be a time average if the statistical parameters are stationary.

0 8 change to read: "…where $\sigma_{\mathrm{b}k}$ is the expected backscattering cross section of the k^{th} hydrometeor (expectations computed over the ensemble of cross sections for the k^{th} scatterer), it follows …

116 At the end of section 5.2, add the following paragraph:
In this section we assumed scatterers follow exactly the air motion. But usually scatterers are hydrometeors that fall in air, have different fall speeds because of their different sizes, and change orientation, and vibrate (if they are liquid). These hydrometeor characteristics broaden the Doppler spectrum associated with the velocity field increasing $\sigma_v^2(\vec{r}_o)$ obtained from Eq. (5.51).

118 0 after Eq. (5.75): It should be noted that as $\theta_0 \to 0$, the angular shears in Eq. (5.74) should be replaced by k_θ along the two principal axes of the beam pattern. For example, if the beam is circular symmetric and $\theta_0 = 0$, $\sigma_s^2 = r_o^2 \sigma_\theta^2 [k_\theta^2(\phi = 0) + k_\theta^2(\phi = \pi/2)] + (\sigma_r k_r)^2$.

After Eq. (5.76): It should be noted that if the receiver bandwidth B_6 is much larger than the reciprocal of the pulse width τ, $\sigma_r^2 = \frac{1}{12}\left(\frac{c\tau}{2}\right)^2$.

124-131			to be consistent with notation used in Chapter 5 and that used after page 131, we should change '*k*' to '*m*' and '*m*' to '*l*' wherever it appears in these seven pages.
125	2	1	change to read: "It was explained in Section 5.2.2 that weather…."
		5	change to read: "….assume a Gaussian signal power spectrum plus white noise,
	Eq. (6.3)		Because $S(v)$ is the signal plus noise power spectrum, and because *P* generally defines signal *S* plus *N* power (e.g., 3rd line from bottom of this page), it is suggested $S(v)$ be replaced with $P(v)$.
	Eq. (6.5)		Add subscript 's' to 'ρ' to distinguish the correlation coefficient of the weather signal from the correlation coefficient $\rho_{\mathrm{s+n}}$ of weather signal plus noise to be introduced by Eq. (6.13d) of this supplement.
128	0	2	For clarity, replace ρ_{s} (subscript's' in the book defines the output correlation of a <u>s</u>quare law receiver), here and elsewhere, with $\rho^{(\mathrm{s})}$
	2	4	To place more specificity on the values of *M* and σ_{vn} for which the equation $M_{\mathrm{I}} = 2M\sigma_{\mathrm{vn}}\pi^{1/2}$ is valid, it can be shown that the condition $2.4/M \le \sigma_{\mathrm{vn}} \le 0.25$ applies. Thus in terms of σ_{v} $$4.8v_{\mathrm{N}}/M \le \sigma_{\mathrm{v}} \le v_{\mathrm{N}}/2$$ where v_{N} is the Nyquist velocity (i.e., $\lambda/4T_{\mathrm{s}}$). Thus the larger is *M*, the smaller is the allowed spectrum width to use the simplified expression $M_{\mathrm{I}} = 2M\sigma_{\mathrm{vn}}\pi^{1/2}$. This range of spectrum widths covers most conditions observed with 10 cm wavelength weather radars.
128, Eq.(6.13):			this equation is valid when signal power is much stronger than noise power. Furthermore, in the fourth line of the paragraph leading to this equation, the SD of $\hat{S}$ is only proportional to $\sqrt{\bar{P}^2+\bar{N}^2}$ if the number of independent samples of *P* and *N* are equal; in general this is not the case. For example, noise power in the WSR-88D is estimated independently of the signal power, and its estimate uses many more samples than that used to estimate signal plus noise power. Therefore, the following text, replacing paragraph 3 on p.128, gives the standard deviation of the Logarithm of *Z*(dBZ) estimates as a function of Signal-to-Noise ratio assuming noise is estimated without significant variance.

To estimate reflectivity factor *Z* in presence of receiver noise, receiver noise power *N* needs to be subtracted from the signal plus noise power estimate $\hat{P}$. Thus the Z estimate is $\hat{Z} = \alpha\hat{S} = \alpha(\hat{P} - N)$ where $\hat{P}$ is a uniformly weighted M sample average estimate of the power P at the output of the square law receiver (as in the WSR-88D), and α is a constant calculated from the radar equation. Because N is usually measured during calibration, many more samples are used to obtain its estimate. Therefore its variance is negligibly small, and the noise power estimate can safely be replaced with its expected value N[3]. Z is usually expressed in decibel units; that is, $\hat{Z}(dBZ) = 10\log_{10}\hat{Z} = 10\log_{10}(\alpha\hat{S})$ where $\hat{Z}$ units are mm^6 m^{-3}. The error in decibel units is now derived.

Let $\hat{S}$ the M sample estimate of signal power, be expressed as $\hat{S} = S + \delta S$ where δS is the displacement of $\hat{S}$ from S. Thus

$$\hat{Z}(dBZ) = 10\log_{10}(\alpha S) + 10\log_{10}\left(1 + \frac{\delta S}{S}\right) = Z + \delta Z \qquad (6.13a)$$

Because $\hat{P} = \hat{S} + N$ where N is a constant, $\mathrm{var}[\hat{S}] = \mathrm{var}[\hat{P}] = P^2 / M_{\mathrm{I}}$ (i.e., Eq.6.10). If the number of independent samples M_{I} is sufficiently large so that $\delta S / S$ is small compared to 1, the $\log_{10}$ term in Eq. (6.13a) can be expanded in a Taylor series. Retaining the dominant term of the series, the estimated reflectivity is well approximated by

$$\hat{Z}(dBZ) \approx Z + 4.34\left(\frac{\hat{S}}{S} - 1\right). \qquad (6.13b)$$

Because the first term and the constant 4.34 are not random, the standard error in the estimate $\hat{Z}(dBZ)$ is simply $S.D.[\hat{Z}(dBZ)] = 4.34\, S.D.[\hat{S}/S]$. Because $S.D.[\hat{S}] = S.D.[\hat{P}]$ $= P/\sqrt{M_{\mathrm{I}}} = (S+N)/\sqrt{M_{\mathrm{I}}}$ where M_{I} is the number of independent <u>signal plus noise power samples,</u>

$$S.D.[\hat{Z}(dBZ)] = \frac{4.34\left(1 + \dfrac{N}{S}\right)}{\sqrt{M_{\mathrm{I}}}}. \qquad (6.13c)$$

The M_{I} contained in the M sample set, can be calculated from (6.12) in which $\rho^{(\mathrm{s})}(mT_{\mathrm{s}})$ is replaced by $\rho^{(\mathrm{s})}_{\mathrm{s+n}}(mT_{\mathrm{s}})$ the magnitude of the correlation coefficient of the signal plus noise samples.

The correlation of the input signal plus noise (Eq. 6.4) is normalized by $S + N$ to obtain the correlation *coefficient* of the input signal plus noise power estimates. The correlation

---

3 Although N can be calculated with negligible variance, the expected value can depend, especially for high performance radars such as the WSR-88D, on beam direction and external noise sources factors such as the sun, earth temperature, precipitation, etc.

coefficient of the power samples at the output of the square law receiver is the square of the correlation coefficient of the input power samples, and thus the output signal plus noise power sample correlation coefficient can be written as

$$\rho_{\text{s+n}}^{(\text{s})}(mT_{\text{s}}) = \left(\frac{S}{S+N} \exp\{-2(\sigma_{\text{vn}} \pi m)^2\} + \frac{N}{S+N} \delta_m \right)^2 \tag{6.13d}$$

This correlation coefficient can be substituted into (6.12) in place of $\rho^{(\text{s})}(MT_s)$, and the sum numerically evaluated to obtain M_{I}. If this result is substituted into (6.13c) we obtain a solution for the standard error (in d*BZ* units) of the reflectivity factor as a function of the number of samples *M*, the normalized width, σ_{vn} of the weather signal's Doppler spectrum, and the signal to noise ratio *S*/*N*.

Alternative to a numerical solution, there are conditions whereby we can obtain a useful analytical solution. It can be shown the condition $\sigma_{\text{vn}} \le 0.25$ still applies to replace the sum in Eq. (6.12) by an integral even if $N \ne 0$; furthermore, $\sigma_{\text{vn}} \ge 2.4/M$ becomes a sufficient condition to ignore the term $|m|/M$ in that equation. Because the dwell time MT_s is typically much longer than the correlation time of the weather signal samples, $\rho_{s+n}(MT_s) << 1$ and thus the limits on the integral can be extended to infinity. Evaluation of this integral under these conditions yields

$$M_{\text{I}} = \frac{\left(1+\frac{S}{N}\right)^2 M}{1 + 2\frac{S}{N} + \frac{(S/N)^2}{2\sigma_{\text{vn}}\sqrt{\pi}}} \tag{6.13e}$$

The formula for calculating the standard error in estimating *Z*(d*BZ*) as a function of *S*/*N* is obtained by substituting (6.13e) into (6.13c) yielding

$$S.D.[\hat{Z}(dBZ)] = \frac{4.34}{\sqrt{M}} \frac{N}{S} \left(1 + 2\frac{S}{N} + \frac{(S/N)^2}{2\sigma_{\text{vn}}\sqrt{\pi}} \right)^{1/2} dB\,, \tag{6.13f}$$

a result agreeing with that obtained from simulation (Melnikov, 2010)[4]. Although $S.D.[\hat{Z}(dBZ)]$ increases without bound as *S/N* decreases, it can be shown S.D. of $\hat{Z}$ estimates, expressed in linear units (e.g., $\text{mm}^6\ \text{m}^{-3}$), decreases as *S/N* decreases (i.e., $S.D.[\hat{Z}(\text{mm}^6\text{m}^{-3})] = \alpha N/\sqrt{M}$ if *S* = 0; in this case $\hat{Z}$ = 0)! This apparent dichotomy is explained by the fact that the slope of the logarithmic function increases without bound as its argument decreases. That is, a constant width of a distribution on the linear scale increases on the logarithmic scale as the mean decreases.

4 Melnikov, M., c.a. 2010 "Determining Polarimetric Properties of Bragg Scatterers and Convective Boundary Layer Thickness using a WSR-88D", Unpublished manuscript; Personal Communication..

133 (6.20a) A slightly more rigorous condition based upon the correlation function for the linear receiver (condition 6.20a was derived based on power estimates using a square law receiver) and estimation of the first and second moments is: $\sqrt{2\pi}M\sigma_{\mathrm{vn}} >> 1$.

136 4 1-5 The form of Eq.(6.29) was first presented by Rummler (1968). *But this form does not follow directly from Eq.(6.27) as is stated in the sentences preceding Eq.(6.29)*. Thus it would be more proper to change these lines to read:

"If spectra are not Gaussian, Rummler (1968) has derived an estimator valid for small spectrum widths (i.e. $\sigma_{\mathrm{vn}} << 1$). This estimator is

(6.29)

At large widths Eq. (6.29) has an asymptotic ($M \rightarrow \infty$) negative bias which causes an underestimate of the true spectrum width (Zrnić, 1977b), whereas .... spectrum is Gaussian)"

Added Reference:

Rummler, W. D. (1968), Introduction of a New Estimator for Velocity Spectral Parameters. *Technical Memorandum, April 3, 1968.* Bell Laboratories, Whippany, New Jersey 07981.

150 1 8 change to read: wavenumber $k = 2\pi / \lambda$ of the precipitation-free atmosphere. It is assumed the atmosphere is homogeneous, otherwise k and λ would also be a function of r.

195 2 1-3 change to read: "Three parameters of interest…… integration, (2) the effective beamwidth, and (3) the effective pattern shape."

195-196 To be consistent with notation used elsewhere, and because on these pages we exclusively use the term "effective" instead of "apparent" when we describe patterns broadened by azimuthal scanning, use the subscript "e" instead of "a" on $f_a(\phi - \phi_0)$ and ϕ_{a}.

196 1 1&7 replace ϕ_{a} with $\theta_{1\mathrm{e}}$.

1 at the end of this paragraph add the sentence: "If $\alpha MT_{\mathrm{s}} \le \theta_1$, the effective normalized pattern retains a Gaussian shape, but if $\alpha MT_{\mathrm{s}} >> \theta_1$, the pattern shape is roughly trapezoidal having amplitude $(\alpha MT_{\mathrm{s}})^{-1}$, and a one-way half-power width of about αMT_{s}."

2 3&5 replace ϕ_{a} here and in Fig. (7.25) with $\theta_{1\mathrm{e}}$.

212 0 Add at the end of this paragraph: More recently Clothiaux et al. (JTECH, 1995) present cloud reflectivities much weaker than those reported by Gossard and Strauch (1983). Clothiaux et al. calculated cloud reflectivity factors using published in situ measurements of mean droplet diameter and liquid water content, and assumed a gamma drop diameter distribution with a shape factor of 18 (i.e., the distribution is nearly normal). Clothiaux et al., found that continental cumulus has Z values ranging from -28 to -15 dBZ (3 cases); -35 to -38 dBZ for continental stratocumulus (2 cases); -35 to -15 dBZ for marine stratocumulus (22 cases); and the weakest reflectivity -52 to -30 dBZ is associated with altocumulus clouds (5 cases).

240 3 After Eq.(8.43a), insert: Herein we assume the weighting function $F(\boldsymbol{r}_n)$ is identical for horizontal and vertically polarized waves, and that each is purely transmitted (i.e., no cross-polar component is present).

241 0 at the end of this paragraph add: That is, $n(\boldsymbol{r})dV$ is the number of scatterers in the differential volume dV at $\boldsymbol{r}$, wherein every one of these scatterers has the same ensemble average $< s_{ij}s_{kl}^* >$! It might seem strange to assign the same $< s_{ij}s_{kl}^* >$ to drops of all sizes and shapes in dV, but it must be realized that we do not know the size and shape of each scatterer. The best we can do is estimate the expected size and shape of each of the scatterers. This expectation operation is further discussed and interpreted in the discussion of Eq. (8.45b) presented below.

Eq.(8.45) To avoid confusion with the N associated with the Drop Size Distribution (DSD), and because the scatterer properties do depend on location, replace $N(\mathbf{X})$ with $p(\mathbf{X}, \boldsymbol{r})$. Also change equation number to (8.45a).

242 0 Change $N(\mathbf{X})$ to $p(\mathbf{X}, \boldsymbol{r})$ and add, at the end of this paragraph, the following: As shown in section 8.5.2.4, the scattering matrix elements s_{ij} are functions of D_e, drop shape, canting angle, etc. Shape is related to D_e, and if the canting angle of each scatterer is zero, $p(\mathbf{X}, \boldsymbol{r})$ is only a function of D_e and $\boldsymbol{r}$. Under these conditions we have the simplified equation

$$p(D_e, \boldsymbol{r}) = \frac{N(D_e, \boldsymbol{r})}{\int_0^\infty N(D_e, \boldsymbol{r}) dD_e} = \frac{N(D_e, \boldsymbol{r})}{n(\boldsymbol{r})}. \tag{8.45b}$$

Thus (8,44a) can also be written as

$$< V_{ij}V_{kl}^* > = \int_V |F(\mathbf{r})|^2 \int_0^\infty s_{ij}s_{kl}^* N(D_e, \mathbf{r}) dD_e dV. \tag{8.45c}$$

			Given the drop size distribution, the inner integral in (8.45c) can be directly evaluated, at least in principle. This integral is defined as $< s_{ij} s_{kl}^* >_{dV}$ which represents a complex element of the scattering matrix *per unit volume* (analogous to reflectivity η, the backscattering cross section per unit volume, section 4.4), and $< s_{ij} s_{kl}^* >_{dV} = n(\mathbf{r}) < s_{ij} s_{kl}^* >$.
242	2		The scattering matrix elements in Eq.(8.46) are $< s_{hh} s_{vv}^* >_{dV} = n(\mathbf{r}) < s_{ij} s_{kl}^* >$; to simplify notation we have drop the subscript "*dV*".
243	2	5	based upon IEEE standard notations, change "co-polar" to "copolar" here and everywhere co-polar appears.
244	0	1	change to read: "…attenuation is, at 10-cm wavelengths, rather…."
		6	change to read: "…differential phase shift ϕ_{DS} upon backscatter (section 6.8.2.2) and the differential phase shift of the propagating waves, it is…"
		8	change to read: "Thus the correlation $\langle V_{\mathrm{hh}}^* V_{\mathrm{vv}} \rangle / \sqrt{\langle \lvert V_{\mathrm{hh}} \rvert^2 \rangle \langle \lvert V_{\mathrm{vv}} \rvert^2 \rangle}$ of the copolar…."; likewise in the line after Eq. (8.49a) insert expressions analogous to that as above to emphasize these formulas are based on measurements using voltages in the receiver.
	0		replace the period with a comma after Eq. (8.49c) and add after this equation: "where the differential phase shifts upon scattering (i.e., δ_{hh} - δ_{vv}, δ_{vv} - δ_{hv}, δ_{hh} - δ_{hv}), are part of ρ_{hv}, ρ_v, and ρ_h.
Eq. (8.49)			In deriving these equations it is assumed propagating waves only have extra mean phase shift and amplitude change due to precipitation along the path to and from the scattering volume (i.e., there are no added random fluctuations in amplitude and phase along the path). This conclusion is rooted in our implicit assumption that multiple scatter can be ignored (i.e., the Born approximation).
Eq. (8.51)			Here we define ϕ_{DP} as the two-way propagation differential phase, whereas in the equation after Eq. (6.52), ϕ_{DP} includes the differential phase shift ϕ_{DS} upon scattering.
255	1	2	Recent data from a disdrometer show as much as a factor of 3 error
391	0	2	it should be noted that the correlation scale ρ_0 is not the same as the

integral scale ρ_I which is defined as

$$\rho_I = \int_0^\infty \frac{R(\rho)}{R(0)} d\rho$$

For the correlation function given by Eq. (10.19), ρ_0 is related to ρ_I as

$$\rho_I = \frac{\Gamma(\nu + 0.5)\Gamma(0.5)}{\Gamma(\nu)} \rho_0$$

398 Section 10.2.1: we introduce the variable $\Phi_v(\mathbf{K})$, the spatial spectrum of point velocities, in Eq.(10.46) but define it in the paragraph following its introduction (i.e., in Eq. 10.48). We should label (10.48) as (10.46), and place it before Eq.(10.46) and label it as (10.47). Other adjustments should be made to correct equation numbers; these should be few.

399 0 1 add the parenthetical phrase "(i.e., spectra of <u>radial</u> velocities along a radial and transverse to the direction of advecting turbulence)"

403 1 6 For a fuller explanation of the steps in Section 10.2.2, and using notation consistent with that used in earlier chapters (i.e., using E[x] instead of <x> to denote the expected value), we offer the following revision of section 10.2.2:

In this section we define the relationship between the variance of radial velocities at a *point* and the expected spectrum width measured by radar (Rogers and Tripp, 1964). Let the variance of the radial velocity $v(\boldsymbol{r}, t)$ at a point be σ_p^2. This variance is the sum of the variance at all velocity scales and is defined by the equation,

$$\sigma_p^2 = E_v[v^2(\boldsymbol{r},t)] - E_v^2[v(\boldsymbol{r},t)] \qquad (10.55)$$

where $E_v[x]$ indicates an expectation, or an average over a complete <u>ensemble of velocity fields</u>, all having the same statistical properties. Assume that steady wind is not present, the radar beam is fixed, and hydrometeors do not oscillate or wobble and are perfect tracers of the wind. In this case, turbulence is the only mechanism contributing to spectral broadening, and it is a random variable having zero mean (i.e., $E_v[v(\boldsymbol{r}, t)] = 0$).

The second central moment, σ_v^2, of the Doppler spectrum associated with turbulence can be obtained from Eq. (5.51). Although Eq. (5.51) was derived under the assumption that $v(\boldsymbol{r}, t)$ is steady, this equation can be applied to the time varying wind produced by turbulence. But then σ_v^2 would be a time varying quantity because $v(\boldsymbol{r}, t)$ is now a time dependent variable. Replacing subscript 'v' with 't' for pure turbulence, we obtain,

$$\sigma_v^2(t) = \sigma_t^2(t) = \overline{[v(\boldsymbol{r},t) - \overline{v(\boldsymbol{r},t)}]^2} = \overline{v^2(\boldsymbol{r},t)} - \overline{v(\boldsymbol{r},t)}^2 \qquad (10.56)$$

where $\overline{\sigma_{\mathrm{t}}^2(\boldsymbol{r},t)}$ is the expected instantaneous second central moment of the Doppler spectrum associated with turbulence. Although $\sigma_v^2(t)$ is a function of $\boldsymbol{r}_0$, the location of the V_6, we have omitted $\boldsymbol{r}_0$ to simplify notation; nevertheless, the argument $\boldsymbol{r}_0$ is implicit in $\sigma_{\mathrm{v}}^2(t)$. The overbar denotes a spatial average weighted by the normalized function $H_{\mathrm{n}}(\boldsymbol{r}_0,\boldsymbol{r})$ where

$$H_{\mathrm{n}}(\boldsymbol{r}_0,\boldsymbol{r}) = \frac{I(\boldsymbol{r}_0,\boldsymbol{r})\eta(\boldsymbol{r})}{\iiint I(\boldsymbol{r}_0,\boldsymbol{r})\eta(\boldsymbol{r})dV}$$

is a combination of reflectivity $\eta(\boldsymbol{r})$ and antenna pattern weights. Because the focus in this section is on the time changing velocity field we assume $\eta(\boldsymbol{r})$ to be time independent.

Note that $\sigma_{\mathrm{t}}^2(t)$ is the <u>expected</u> instantaneous second central moment of the Doppler spectrum. In this case, however, the expectation, $E_\xi[x]$, is over ensembles of scatterer configurations ξ (Doviak and Zrnic, 1993, p.108) each having the same velocity field, whereas the expectation in Eq. (10.55) is taken over ensembles of velocity fields. The, expectations $E_\xi[x]$ can be made, at least in principle, over ensembles of ξ while $\hat{v}(\boldsymbol{r},t_n)$ is frozen. Different scatterer configurations can be obtained by reshuffling scatterer locations. Moreover, although we can in principle freeze the velocity field, scatterers can have differential motion that results in a changing scatterer configuration. This in turn results in changes in the weather signal, and thus fluctuations of the <u>estimates</u> $\hat{\sigma}_{\mathrm{t}}^2(t_n)$ of $\sigma_{\mathrm{t}}^2(t_n)$. The circumflex ^ denotes the estimate made from weather signal samples obtained during a dwell-time, T_d, and 't_n' denotes the n^{th} dwell-time, the short time span of duration MT_s, typically less than 1s. Even though estimate variance associated with different configurations of scatterers is removed by a ξ average, we retain the circumflex '^' <u>to emphasize</u> the estimated value in this section pertains to one member of the ensemble of velocity fields at the n^{th} dwell-time.

The time dependence of $\hat{\sigma}_{\mathrm{t}}^2(t)$ (i.e., of $E_\xi[\hat{\sigma}_{\mathrm{t}}^2(t_n)]$; henceforth the expectation over ξ will not be explicitly shown) is also due to changes of turbulence on scales large compared to V_6 dimensions. Large scales of turbulence are said to create shear across V_6. In this case large scale turbulence contributes a time varying shear component to $\hat{\sigma}_t^2(t)$ that can cause significant fluctuations of $\hat{\sigma}_{\mathrm{t}}^2(t)$. Usually we are not interested in the detailed time dependence of $\hat{\sigma}_{\mathrm{t}}^2(t)$, but in its statistical properties such as its mean or expected value, (i.e., $E_{\mathrm{v}}[\hat{\sigma}_{\mathrm{t}}^2(t_n)]$), its auto-correlation function, etc. In this section we show how $E_{\mathrm{v}}[\hat{\sigma}_t^2(t_n)]$ is related to the energy density E of turbulence.

The $H_{\mathrm{n}}(\boldsymbol{r})$ weighted radial velocity $\overline{\hat{v}(\boldsymbol{r},t_n)}$ is defined as the first moment $\hat{v}_m(t_n)$ of the Doppler spectrum estimated from weather signal samples collected during T_d. The variance of $\hat{v}_m(t_n)$ is, by definition, given by

$$\mathrm{var}\left[\hat{v}_m(t_n)\right] \equiv E_{\mathrm{v}}\left[\hat{v}_m^2(t_n)\right] - E_{\mathrm{v}}^2\left[\hat{v}_m(t_n)\right] \equiv \sigma_{\bar{\mathrm{v}}}^2(t_n)\,. \tag{10.57a}$$

For pure turbulence, $E_{\mathrm{v}}\left[\hat{v}_m(t_n)\right] = 0$ and thus

$$\sigma_{\bar{\mathrm{v}}}^2(t_n) = E_{\mathrm{v}}\left[\hat{v}_m^2(t_n)\right]. \tag{10.57b}$$

Because (10.56) applies to one member of an ensemble of velocity fields, we express (10.56) as

$$\hat{\sigma}_{\mathrm{t}}^2(t) = \overline{[\hat{v}(\boldsymbol{r},t) - \overline{\hat{v}(\boldsymbol{r},t)}]^2} = \overline{\hat{v}^2(\boldsymbol{r},t)} - \overline{\hat{v}(\boldsymbol{r},t)}^2$$

Where the diacritical simply emphasizes that $\hat{\sigma}_t^2(t)$ is an estimate for one T_d which essentially samples the velocity field. By taking the velocity ensemble average of this equation and substituting Eq. (10.57b) into it, we obtain, after commuting ensemble and spatial averages (i.e., $E_{\mathrm{v}}\left[\overline{v^2(\boldsymbol{r},t_n)}\right] \equiv \overline{E_{\mathrm{v}}[v^2(\boldsymbol{r},t_n)]}$),

$$E_{\mathrm{v}}\left[\overline{\hat{\sigma}_t^2(t_n)}\right] + \sigma_{\bar{\mathrm{v}}}^2(t_n) = \overline{E_{\mathrm{v}}[\hat{v}^2(\boldsymbol{r},t_n)]}. \tag{10.58a}$$

The weighted spatial average of $E_v[\hat{v}^2(\boldsymbol{r},t_n)]$ is, by definition,

$$\overline{E_{\mathrm{v}}[\hat{v}^2(\boldsymbol{r},t_n)]} = \int_V E_{\mathrm{v}}[\hat{v}^2(\boldsymbol{r},t_n)] H_{\mathrm{n}}(\boldsymbol{r}_0,\boldsymbol{r})\,dV \tag{10.58b}$$

The derivation leading to Eq. (10.58) does not require turbulence to be statistically stationary, homogeneous, or isotropic. That is, Eq. (10.58a) relates the expected value of the second central moment of measured Doppler spectra (i.e., measured estimated with short dwell-times), and the variance of the mean Doppler velocity, to the $H_{\mathrm{n}}(\boldsymbol{r}_0,\boldsymbol{r})$ weighted spatial average of the expected value of the second central moment of the <u>radial</u> component of turbulence at <u>each</u> point $\boldsymbol{r}$ and t_n. This is in agreement with results of Rogers and Tripp (1964).

These results apply to estimates of the Doppler velocity and second central moments made with any dwell-time. If longer dwell-times are used, $E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}\right]$ increases because velocity components associated with large scale turbulence have time to evolve within the resolution volume and be adequately sampled. On the other hand, the variance $\sigma_{\bar{\mathrm{v}}}^2$ of the mean Doppler velocity decreases as dwell time increases, and it vanishes in the limit of an infinite dwell time. In this limit, $\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}$ solely measures the spatial average of the weighted distribution of turbulence at each point.

10.2.2.1 Estimate variance due to changes in scatterer configuration

It should be noted that the variance, $\sigma_{\bar{v}}^2(t_n)$, does not include the variance associated with the statistical uncertainty due to changing scatterer configurations. Nevertheless, variance (e.g., that discussed in Chapter 6) associated with the weather signal fluctuations due to changes in the scatterer configuration can be significant, and it needs to be included in any rigorous analysis of radar measurements of turbulence.

For example, in addition to the variance of $\overline{\hat{v}(\boldsymbol{r},t_n)}$ due to the time changing velocity field, we have additional variance associated with the random location of scatterers (i.e., the time dependence of the true $\overline{\hat{v}(\boldsymbol{r},t_n)}$ differs from the time dependent $\overline{\hat{v}(\boldsymbol{r},t_n)_R}$ estimated with radar). Here $\overline{\hat{v}(\boldsymbol{r},t_n)}$ is the weighted velocity irrespective of the scatterer configuration.

Even if $\hat{v}(\boldsymbol{r},t_n)$ was a constant independent of time, the radar estimates $\overline{\hat{v}(\boldsymbol{r},t_n)_R}$ would be fluctuating due to the fact that scatterers move continuously to new locations for the same velocity field. That is, there is an evolving configuration of scatterers, and each configuration of scatterers produces a different weather signal sample from which $\overline{\hat{v}(\boldsymbol{r},t_n)}$ is estimated. In general, time fluctuations of estimates are due to both a changing velocity field and a changing configuration of scatterers.

To illustrate, assume a constant wind that carries scatterers along range arcs. In this case, the radial velocity field $\overline{\hat{v}(\boldsymbol{r},t_n)} = 0$. Nevertheless, radar estimates of $\overline{\hat{v}(\boldsymbol{r},t_n)}$ are time varying and random; this is so because the scatterers' configuration within V_6 continually changes as new scatterers enter V_6, and others leave it. That is, the In-phase, *I*, and Quadrature, *Q*, components of the weather signal are still Gaussian distributed random variables as shown in Fig. 4.4a. In other words, although the mean or expected Doppler velocity is zero, the time sequence of the *I, Q*, samples will randomly move in the *I, Q* plane, and Doppler velocity estimates made with a small number of samples (e.g., two) can have non zero values.

The changes of *I, Q* from sample pair to sample pair can be relatively small if the sample pair spacing is short compared to the correlation time τ_c of the weather signals, and if the intra-pulse spacing $T_s << \tau_c$. The weather signal correlation time τ_c, equal to the time required to flush V_6 with new scatterers, is not necessarily equal to the correlation time of the velocity field; in our simple illustration the correlation time of the velocity field is infinite. The non zero velocity estimates, calculated from pairs of *I, Q* samples, are uncorrelated if the pair spacing is longer than τ_c. Only with a long time average will these velocity estimates average to 0.

These arguments, applied to the radar estimates of $\overline{\hat{v}(\boldsymbol{r},t_n)}$, can also be applied to show that the ξ expectation of the radar estimates $\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)_{\mathrm{R}}}$ {i.e., $E_{\xi}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)_{\mathrm{R}}}\right]$} equals $\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}$.

10.2.2.2 Homogeneous turbulence

If turbulence is homogeneous over the region where the weighting functions contribute significantly (i.e., turbulence is locally homogeneous), Eq. (10.58b) shows that $\overline{E_{\mathrm{v}}[\hat{v}^2(\boldsymbol{r},t)]}$ = $\sigma_{\mathrm{p}}^2(t_n)$, the "point-measured variance" (Frisch and Clifford, 1974; the following paragraph will clarify what is meant by "point-measured variance"). The radial component of the turbulent energy density at a point is, $\mathcal{E}_r = \frac{1}{2}\gamma\sigma_{\mathrm{p}}^2$, where γ is the air mass density. Using Eq. (10.58a), and noting that $\overline{E_{\mathrm{v}}[\hat{v}^2(\boldsymbol{r},t_n)]} = \sigma_{\mathrm{p}}^2(t_n)$, we can then relate $\mathcal{E}_r$ to radar measurements as

$$\mathcal{E}_r = \frac{1}{2}\gamma\sigma_{\mathrm{p}}^2(t_n) = \frac{\gamma}{2}\left\{E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}\right] + \sigma_{\bar{\mathrm{v}}}^2(t_n)\right\}. \tag{10.59}$$

If turbulence is isotropic, the total turbulence energy density $\mathcal{E} = 3\mathcal{E}_r$.

Eq. (10.59), establishes a relation between the radial component of the "point-measured" turbulent energy density and the second central moment of the Doppler spectrum associated with turbulence, but it requires turbulence to be *locally* homogeneous although not isotropic or stationary. Therefore, the "point" under discussion is, in reality, a collection of points over the entire resolution volume wherein turbulence is assumed to have the same statistical properties at each point. Section 10.2.2.3 presents results for the case where turbulence is inhomogeneous.

Eq. (10.59) demonstrates that the energy density of the radial component of "point-measured" homogeneous turbulence can be calculated from the sum of the expected value of the second central moment, $E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}\right]$, and the variance, $\sigma_{\bar{\mathrm{v}}}^2 = E_{\mathrm{v}}\left[\overline{\hat{v}(\boldsymbol{r},t_n)}^2\right]$, of the mean Doppler velocity estimates. It also shows how that energy is partitioned between large and small scales of turbulence; $\sigma_{\bar{\mathrm{v}}}^2$ is principally due to large scale turbulence whereas $E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}\right]$ is principally due to small scale turbulence.

If the radial component of turbulence has a -5/3rds power law vs wavenumber $K = 2\pi/\Lambda$ for all wavelengths Λ of the spectrum of turbulence, and if the dimensions of V_6 are the same in all directions (i.e., $\sigma_\theta r_o = \sigma_\phi(\theta_0)r_o = \sigma_r$; section 5.3), it can be shown that turbulence from all $\Lambda \le L_c \equiv \sigma_\theta r_o$, the characteristic size of V_6, contributes only about 20% to $E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}\right]$. Thus, although some portion of $E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}\right]$ is due to small scales, most of its contribution comes from turbulence on wavelengths large compared to L_c; this appears at variance with previously published interpretations. For example, if the weighting function is uniform, as stipulated by Rogers and Tripp (1964), across V_6 having dimensions $LxLxL$, only 36% of $E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}\right]$ is due to turbulence from all $\Lambda \le L$. This contradicts Rogers and Tripp (1964) statement that $E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^2(\boldsymbol{r},t_n)}\right]$ "receives spectral contributions mainly from the wavelengths shorter than the dimensions of V_6".

Large scale (i.e., large compared to V_6 dimensions) turbulence shifts the Doppler spectrum along the velocity axis so that the single spectrum mean Doppler velocity changes from one spectrum to the next. Thus to estimate $E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^{2}(\boldsymbol{r},t_n)}\right]$ we need to average the second central moments calculated about each of the fluctuating means. For stationary and/or globally homogeneous turbulence, expectations can be obtained from averages over time and/or space (i.e., at different $\boldsymbol{r}_0$ locations).

10.2.2.3 Inhomogeneous turbulence

It is not necessary to assume turbulence is homogeneous (as we did in arriving at Eq. 10.59) to obtain a relation between the point variance of the radial component of turbulence and radar measurements. If turbulence is not homogeneous, $\sigma_{\mathrm{p}}^{2}(\boldsymbol{r},t_n)$ is still the variance at a point $\boldsymbol{r}$, but $\overline{\sigma_{\mathrm{p}}^{2}(\boldsymbol{r},t_n)}$ is the $H_{\mathrm{n}}(\boldsymbol{r}_0,\boldsymbol{r})$ weighted spatial average wind variance at each point. Then the expression for the point variance must be written as,

$$\overline{\sigma_{\mathrm{p}}^{2}(\boldsymbol{r},t_n)} = E_{\mathrm{v}}\left[\overline{\hat{\sigma}_{\mathrm{t}}^{2}(\boldsymbol{r},t_n)}\right] + \sigma_{\bar{\mathrm{v}}}^{2}(t_n)\,.$$

This is exactly the same form as Eq. (10.59), but we now have an overbar on $\sigma_{\mathrm{p}}^{2}(\boldsymbol{r},t_n)$. This simply means that radar can only measure the $H_{\mathrm{n}}(\boldsymbol{r}_0,\boldsymbol{r})$ weighted spatial average of turbulence at each and every point.

As stated earlier (section 10.2.2.1), the variance $\sigma_{\bar{v}}^{2}$ does not include the variance associated with the statistical uncertainty of the estimates of $\overline{v(\boldsymbol{r},t)}$ due to weather signal fluctuations (i.e., the variance associated with changes in the scatterers' configuration). The variance associated with the statistical uncertainty of the estimates must be subtracted from the measured variance in order to obtain $\sigma_{\bar{\mathrm{v}}}^{2}$; window biases, typically associated with the measurements of $\overline{\hat{\sigma}_{\mathrm{t}}^{2}(\boldsymbol{r},t_n)}$ (Doviak and Zrnic, 1984, Fig. 6.8; Melnikov and Doviak, 2002), must also be taken into account.

443 section 11.4.3	to differentiate the commonly known Bragg scatter associated with steady or deterministic perturbations from that Bragg scatter associated with random perturbations, we introduce the term "Stochastic Bragg Scatter" by replacing the second sentence of this section with:

"Perturbations in atmospheric refractive index are caused by temperature and humidity fluctuations; thus the perturbation in n is a random variable having a spectrum of scales. Although there is a spectrum of spatial scales, only those at about the Bragg wavelength $\Lambda_B = \lambda/[2\sin(\theta_s/2)]$ contribute significantly to the backscattered power. Because scatter is from spatial fluctuations in refractive index, the scattering mechanism is herein defined as Stochastic Bragg Scatter (SBS). Because there are temporal fluctuations as well, the scattered power is also a random variable and its properties are related to the statistical properties of the scattering medium. In this section we relate the expected…..(return to the 3rd sentence in the text)"

459 Eq. (11.124) this equation assumes that the beam width is given by Eq. (3.2b). A more general form is

$$\rho_\perp = \frac{D_a\sqrt{2}}{\pi\gamma_1}, \qquad \theta_1 = \gamma_1 \frac{\lambda}{D_a}$$

4 at the end of this paragraph, "...in this section.", add: "Under far field conditions the beamwidth part of the "resolution volume weighting" term in Eq.(11.122) does not contribute significantly to the integral, but beamwidth and range resolution do contribute to the backscattered power because they multiply the integral in Eq.(11.122)."

460 0 2 add the following sentence at the end of the line:
ρ_h is the outer scale of the refractive index irregularities, but condition (11.124) applies to the transverse correlation lengths of the Bragg scatterers. Thus, the conclusion reached in this paragraph applies if the Bragg scatterer's correlation length equals the outer scale.

1 49 The following comments offer an alternative and hopefully better explanation: The angular width (i.e., $\approx \lambda/\rho_B$) of the diffraction pattern for each Bragg scatterer narrows as the correlation length of the Bragg scatterer increases, but reaches a limit $\lambda/2r_F$, where r_F is the first Fresnel zone radius. Because the diffraction pattern's main lobe is centered about the forward scatter direction (i.e., horizontally extended Bragg scatterers displaced horizontally from above the radar, have most significant radiation in a forward scatter direction such that the angle of reflection is equal to the angle of incidence), only those Bragg scatterers within $\lambda z_o/\rho_B$ can contribute significantly to the receiver. The Fresnel term accounts for this diminished contribution from Bragg scatterers.

461 0 11 insert after "...in space.": "This is a consequence of the greater importance of the Fresnel term relative to the resolution volume weighting term (i.e., in Eq.11.122) along the transverse directions."

478	0	7	rewrite the sentence: "Then *g*, now the directional gain (section 3.1.2) is related to…"
513	3	4	rewrite as: "…independent of all others because the shell is assumed to be many wavelengths thick and scatterers are randomly placed in the shell.
547	Index		add: "Antenna; far field, 435-436, 459"
548	Index		add: "Bright band, pp. 256, 268"
554	Index		add "Melting layer, pp. 225, 255"
556	Index		for the entry "Radome losses" add page 43.